Galactic Correlates of Supermassive Black Hole Growth and Their Application

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What Galaxy Properties Drive SMBH Growth?

- Galaxy stellar mass (M_*)
- Star-formation rate (SFR)
- Compactness (e.g., Σ_1)
- Local (sub-Mpc) environment
- Global (1-10 Mpc) environment
- Stellar-population age

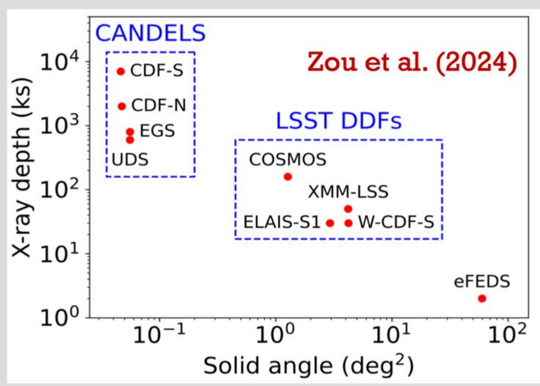
Surveys Used and Techniques

Table 1. Basic Information for the Fields Used in This Work

Field	Area (deg^2)	m_{lim} (AB mag)	X-ray Depth (ks)	X-ray ref.	Galaxy ref.	Photo-z ref.	AGN	Galaxies	(a, b)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
GOODS-S	0.05	26.5 (H)	7000 (Chandra)	5	1	4,8	224 (111)	4144	(−15.87, 2.63)
GOODS-N	0.05	26.5 (H)	2000 (Chandra)	8	1	1,11	174 (167)	4603	(−15.49, 2.58)
EGS	0.06	26.5 (H)	800 (Chandra)	6	1	9	112 (10)	5889	(−15.13, 3.08)
UDS	0.06	26.5 (H)	600 (Chandra)	4	1	8	117 (25)	5010	(−15.05, 4.90)
COSMOS	1.27	24 (K_s)	160 (Chandra)	3	2	5,10	1459 (880)	86765	(−14.68, 5.19)
ELAIS-S1	2.93	23.5 (K_s)	30 (XMM-Newton)	7	3	6,12	676 (261)	157791	(−13.90, 4.57)
W-CDF-S	4.23	23.5 (K_s)	30 (XMM-Newton)	7	3	6,12	872 (311)	210727	(−13.86, 4.97)
XMM-LSS	4.20	23.5 (K_s)	40 (XMM-Newton)	2	3	2	1765 (898)	254687	(−14.09, 5.36)
eFEDS	59.75	22 (Z)	2 (eROSITA)	1	2	3,7	2667 (1156)	615068	(−13.51, 2.59)

Wedding-cake surveys design

Up to 8000 AGNs in 1.3 million galaxies

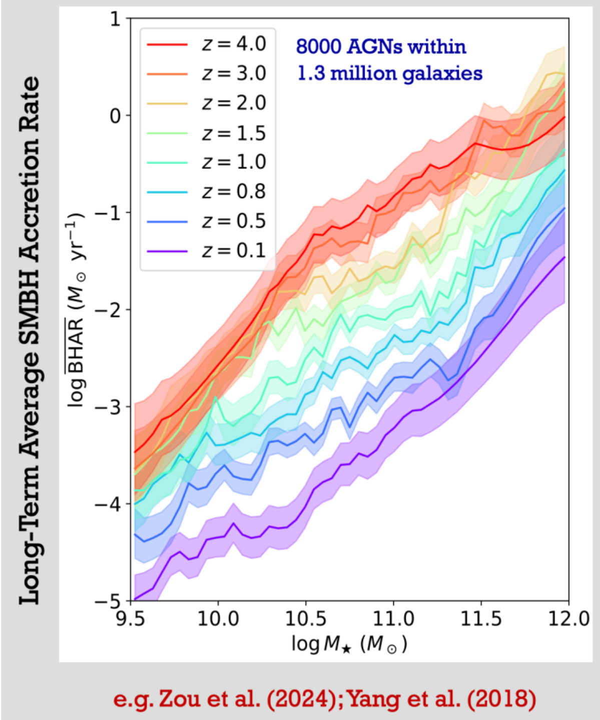


Long-term SMBH growth traced with the X-ray data, by averaging over samples.

Galaxy properties measured from the extensive multiwavelength data via, e.g., FIR-to-X-ray SED fitting.

Non-parametric partial-correlation analyses used to determine what correlations are fundamental.

Stellar Mass

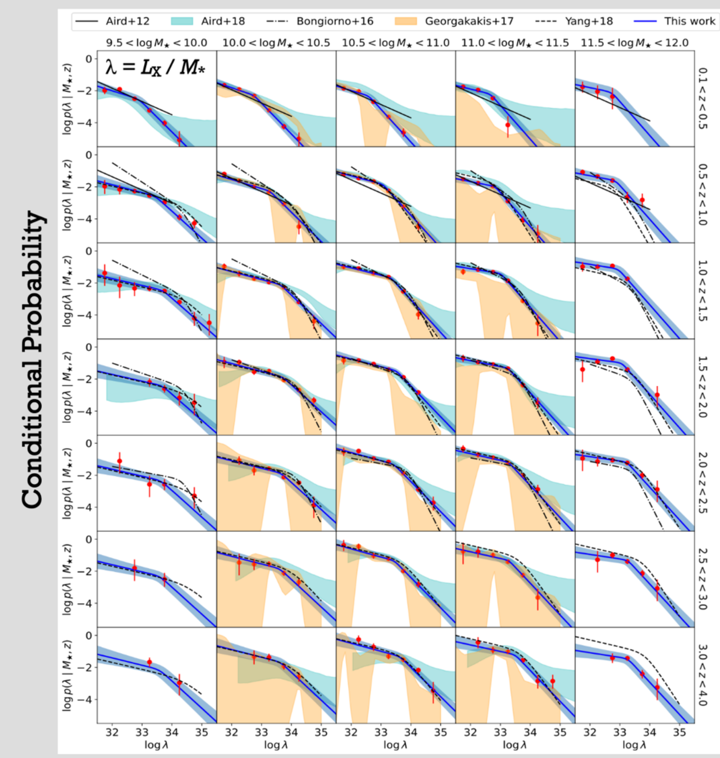


For the general galaxy population at z = 0.1-4, long-term SMBH growth correlates most strongly with M_*.

This dependence spans ~ 3 orders of magnitude in average black-hole accretion rate.

Also note the clear redshift dependence.

Stellar Mass



We also tightly constrain the underlying conditional probability distributions of λ over wide ranges of stellar mass and redshift.

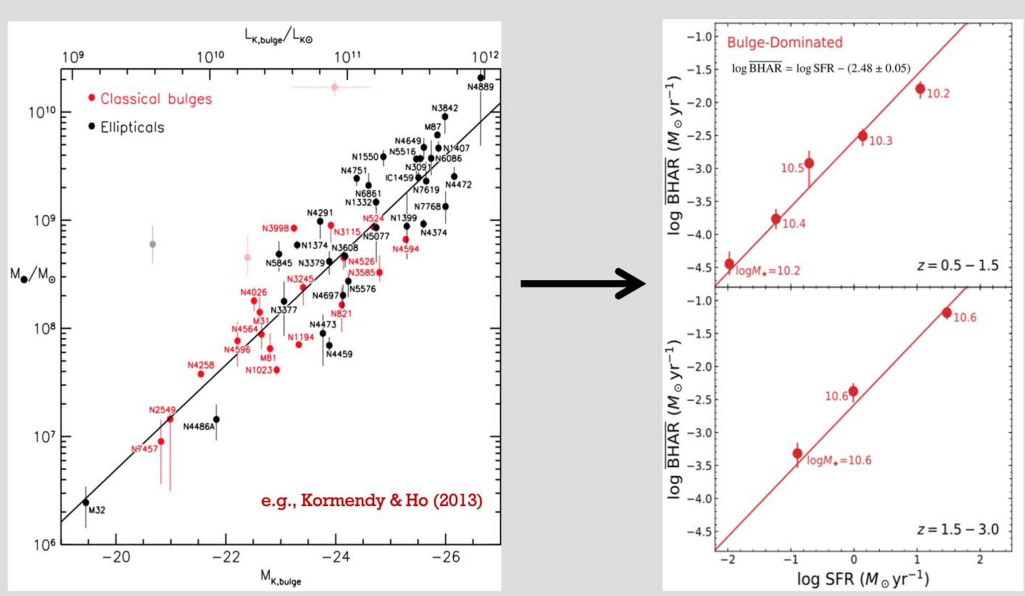
Encodes much information about SMBH growth.

$$\overline{\mathrm{BHAR}}(M_*, z) = \int_{\log \lambda_{\min}}^{+\infty} \frac{(1-\epsilon) k_{\mathrm{bol}}(M_*\lambda) M_* \lambda}{\epsilon c^2} p(\lambda \mid M_*, z) \, d \log \lambda$$

Bulge Star-Formation Rate

M_* tightly related to bulge M_* – but *not* tightly related to total M_* or disk M_*

$$\frac{d}{dt}$$



Yang et al. (2019)

Compactness

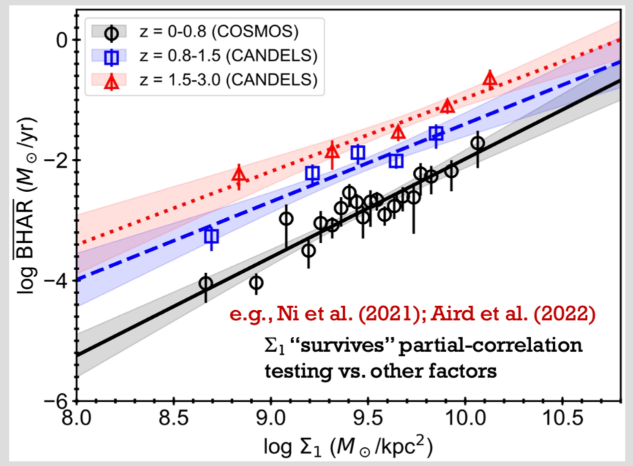
Compactness is a measure of the mass/size ratio of galaxies

$$\Sigma_1 = \frac{M_*(< 1\ \mathrm{kpc})}{\pi\ (1\ \mathrm{kpc})^2}$$

At least for gas-rich, star-forming galaxies, Σ_1 may also serve as a tracer of central-gas density on a kpc-scale.

Compactness Examples for log M_* ~ 10.3

BHAR vs. Compactness for Star-Forming Galaxies



Not seen for quiescent galaxies, suggesting the role of gas density.

Redshift dependence can also be understood via gas evolution.

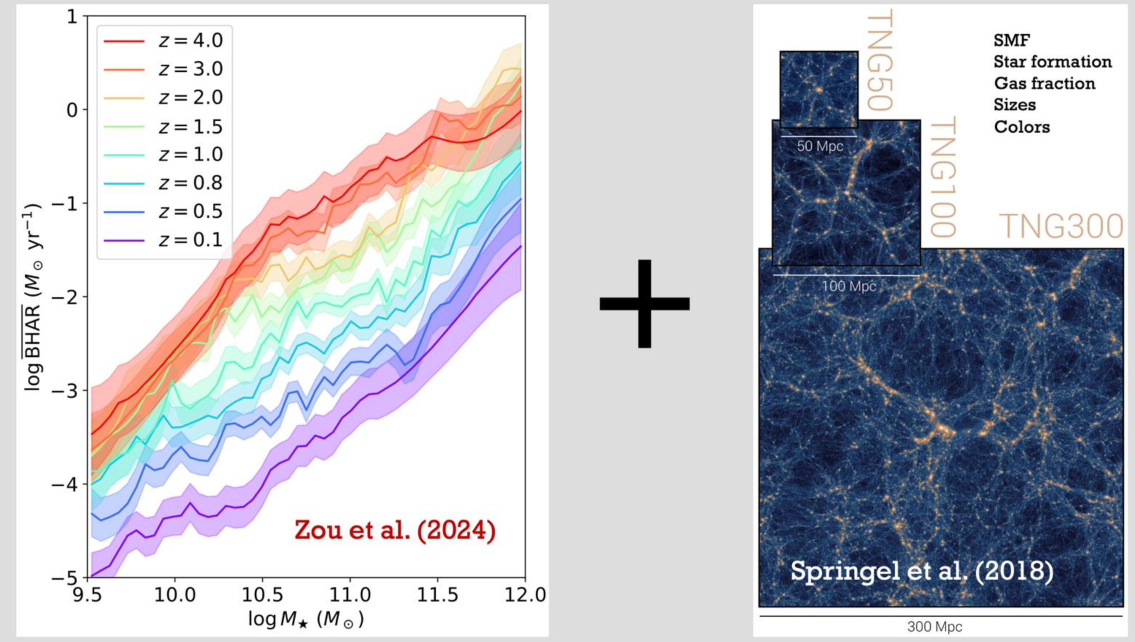
Evolution of the SMBH Population: A Hybrid Approach

Observations constrain accretion channel well (but not yet merger channel).

Simulations provide reasonable merger channel (but unreliable accretion channel).

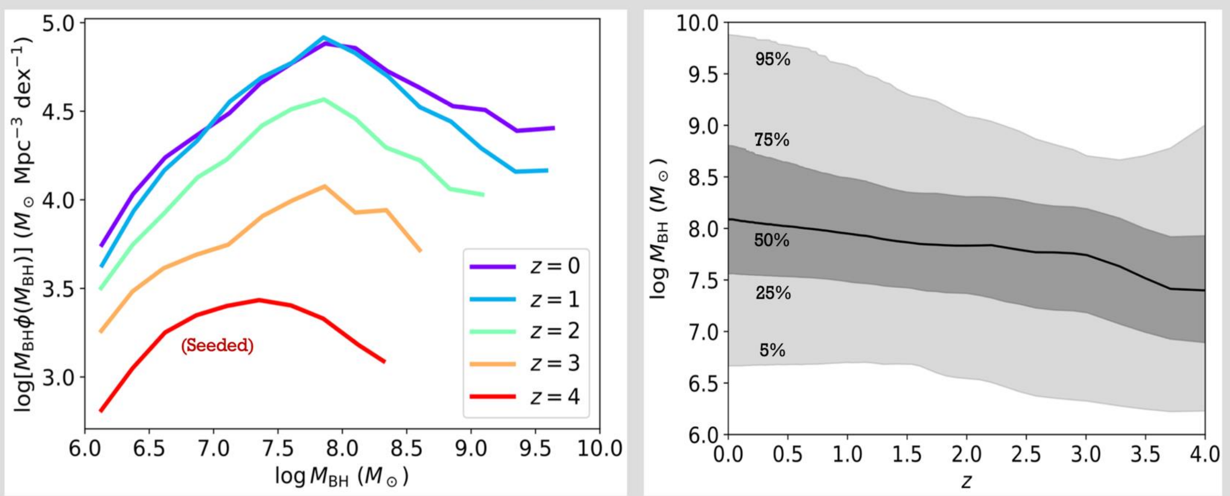
Observed accretion + Simulated mergers

BHAR(M_*, z) + IllustrisTNG



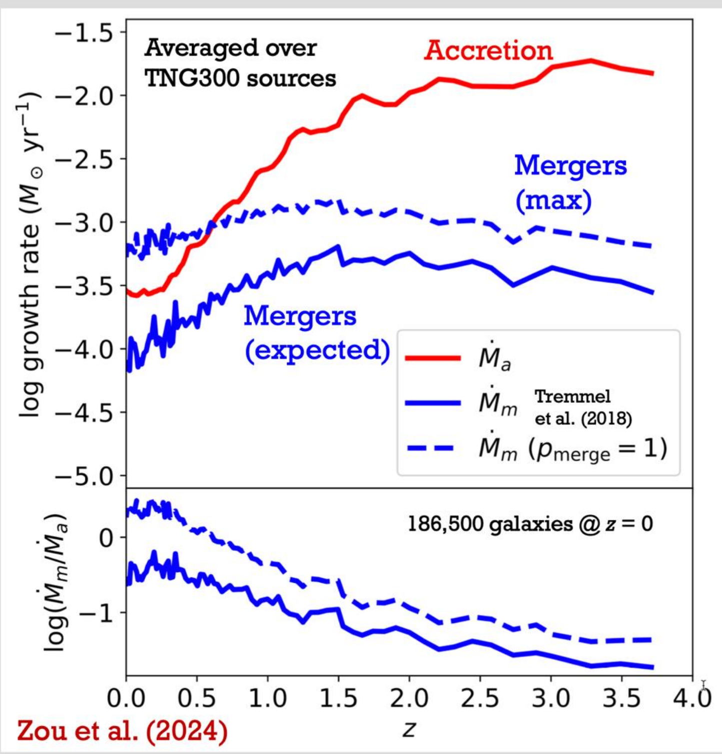
Track SMBH growth at z = 0-4 due to both observed accretion and IllustrisTNG mergers.

SMBH Mass Function



Zou et al. (2024)

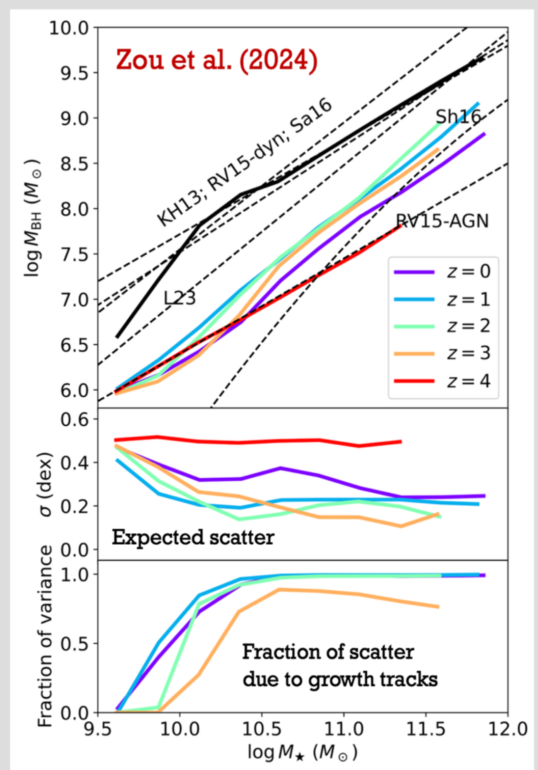
Accretion vs. Mergers



Mergers become increasingly important toward low redshift.

But even at z ~ 0 they most likely contribute at ~ 30% level.

M_{BH}-M_* Relation



Recovered M_{BH}-M_* relation is lower than dynamically measured ones, agreeing better with those from broad-line AGNs.

Agrees better with the "de-biased" relation of Shankar et al. (2016, 2020).

The M_{BH}-M_* relation does not evolve much over z = 0-3, consistent with other constraints.

We also calculate the M_{BH} scatter, which can explain much of the observed scatter.

Future Prospects